Footnotes
The Newsletter of FPRI's Wachman Center
Teaching the History of Innovation: A History Institute for Teachers

By Trudy Kuehner, Reporter

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On October 18-19, 2008, FPRI's **Wachman Center** hosted 40 teachers from 21 states across the country for a weekend of discussion on teaching the history of innovation. The Institute was hosted by the Ewing Marion Kauffman Foundation in Kansas City, Missouri and webcast worldwide. See **www.fpri.org/education/innovation** for videocasts and texts of lectures and classroom lessons.

The **History Institute for Teachers** is co-chaired by **David Eisenhower** and **Walter A. McDougall**.Core support is provided by the Annenberg Foundation and Mr. G.F. Lenfest; funding for the innovation program is provided by the Ewing Marion Kauffman Foundation. The next history weekend is Teaching the Nuclear Age, March 28-29, 2009, at the Atomic Testing Museum in Las Vegas.

Welcoming Remarks

Walter A. McDougall, Co-Chair of FPRI's History Institute and professor of history and international relations at the University of Pennsylvania, noted that while Americans take for granted a frantic pace of change in our material culture, few humanities or social science teachers know much about the process or even the definition of innovation, and few stimulate students to question our faith in "progress." Innovation may in our time not only transform international politics and economics to the point where national measures of power and wealth will become passe, but it may indeed fundamentally alter the relationship of the human species to time, space, and our planet.

Ideas: A History of Thought

Peter Watson of Cambridge University gave the keynote address. He noted that times when mankind has turned inward were periods of great religious, philosophical, and artistic innovation. On the other hand, there are the great turnings out that lead to exploration, science, and innovations in business.

There have been three great accelerations of innovation. The first took place in Mesopotamia around 3,400 BCE and included the invention of writing. The second took place in Europe in the 11th-13th centuries and included the development of the great cathedrals and the first universities. The third took place in Europe between 1750-1950 and included the steam engine, the factory, the spinning jenny, the railway train, etc. These periods of acceleration were all extensions of the evolution of cities.

Intellectual history can also be organized around three big notions: the idea of the soul, the idea of Europe or the West, and the idea of the experiment. The West's countries have long been the most successful in terms of material advantages and political and moral freedoms. Their material advantages bring social and political freedoms in a general process of democratization. These are the fruit of scientific innovations based on observation, experimentation, and deduction. Experimentation is an independent, rational, and democratic form of authority.

The soul has been an even more useful idea. The concept of salvation provided hope to everyone, rich and poor, sinner and saint. It enabled religious authorities to exercise an extraordinary authority, suppressed thought and freedom, and kept the laity enthralled to an educated clericy. Books all but disappeared. The abuses of this were one of the main factors leading to the Reformation.

There are several overlapping theories of why further transformations led to the rise of Europe sometime between 1050 and 1250. First, there are geographical theories. Fernand Braudel holds that Europe benefited from its relatively small size, the efficiency of grain, the climate, and the Mediterranean Sea, which facilitated trade and the exchange of ideas. Douglass North and Robert Thomas argue that, aided by its three great rivers, Europe became the first land mass to fill with people, which permitted wide land ownership and led to specialization, a rise in trade, the spread of markets, the development of the money economy, and growth in technology.

Joseph Needham argues that Europe was actually less stable than China going into this period, because its flexible alphabet system made it easy for tribes to develop mutually incomprehensible languages and because the Mediterranean's peninsulas and archipelagos made Europe more nationalistic. But then Europe benefited from two Chinese inventions, the stirrup and gunpowder, from which China itself did not benefit. Geoffrey Lloyd and Nathan Sivin point out that Chinese scientists were involved in a state concern, which made them more conservative in embracing new ideas.

The final level of explanation concerns changes to Christianity over these years. The common use of Latin permitted unification of thought. Learning shifted from monasteries to cathedrals, from one-on-one teaching to large classes; secular universities too proliferated. Also, as the millennium came and went, people no longer expected Christ to return to earth and save everybody. The idea of personal, individual salvation began to grow, along with first-person literature, personalized art, private studies, and biography. Clocks were adjusted for the seasons, there were innovations in counting, and word order became stabilized. All this concern with accuracy made possible the age of exploration, after which the West was well and truly ahead.

Throughout history, the invention of new forms of energy has brought about major change. The harnessing of fire brought about cooking, ceramics, and smelting. The switch from oxen to horses and watermills helped create the 12th century Renaissance. The adoption of Arab-Latin rigging on Mediterranean ships enabled them to explore the more dangerous Atlantic. The development of steam control brought about the Industrial Revolution. The discovery of the electron created 20th-century technology, culminating in the internet. Ideas have also always followed trade, yet idea proliferation seems to arise where new situations bring about greater individual freedom or where new social arrangements require new forms of cooperation.

The post-WWII genetic research that proved that we are one people who began in Africa around 150,000 years ago, along with globalization and the Internet, could be the next great acceleration. So far, apart from the PC itself and the transistor, all our " new technologies" were invented before WWII. We are actually living in an age of consolidation. The real innovations devolving from globalization have yet to come.

From Stone to Silicon: a Brief Survey of Technology and Inventions

Lawrence Husick, Co-Director of FPRI's Project on Teaching Innovation, explained that"innovation" is not just inventions; it is a *process* of making changes by introducing new methods, ideas, or products. It is the way we extract more value and generate more economic surplus and therefore more leisure time. Disruptive innovations seemingly come out of nowhere to overtake the market leader and become the new standard; sustaining innovations make a product/service/system better incrementally.

What are the 25 most important innovations of all time? Husick noted that there are many methodologies one could use to devise such a list; he ranked his according to the value of the innovation's impact times the total number of lives affected. His list was:

Einstein's work on special relativity and quantum mechanics (25) revolutionized how we look at matter and the universe. Electromagnetism (24) is the idea that we could harness electricity to do work that used to take back-breaking labor by people and animals. Darwin's theory of evolution and natural selection (23) changed the way we view our place in the natural order. The steam engine (22) multiplied man's ability to do work and made practical the coal mining that would provide a primary fuel for the steam engine. Water power (21) permitted one to drive heavy millstones without draft animals.

The concept of science itself (20) only came in the 19th century, before which it was subsumed under natural philosophy. Typesetting (19) goes back to China in 1040, though it was Gutenberg who had the idea of moveable type.

Fossil fuels (18) have been critically important in the last hundred years. Specialization of labor (17) is the idea that some people do some things better than others. By the 16th century, wood pulp paper (16) created an explosion in publishing and the growth of knowledge.

The wheel (15) changed how we move things, how far we could go in a day, and how far we could farm from a village. Formal civil law codes (14) established ways of saying how people should relate to one another commercially; money (13) was a way of solidifying the power of the state; and religion (12) shapes behavior.

Systems of writing (11) made possible written records and calculations. Food preservation (10) meant that you didn't have to eat what you killed right away. Metallurgy (9) began when ancient people noticed hard objects in the bottom of their fire pits; ceramics and pottery (8) derived from the clay the ancients found in the fire pits.

Farming (7) is a long chain of innovation involving the domestication of both animals and plants. Clothing (6) permits us to travel to or live beyond where it's warm and dry. Symbolic communication (5) permits communication across time and space. The lever/simple machine (4) allows people to amplify their mechanical effort, as does the inclined plane simple machine (3).

The taming of fire (2) permitted humans to live in colder places, work after dark, inhabit dangerous places, scare off animals, and cook food. Spoken language (1)—true semantic, syntactic, phonetic language—allowed humans to transmit information about the world from one person to another and underlies all cooperation, the economy, and clan relationships. Finally, Husick offered as innovation 0 (the concept of zero itself having been an innovation) the concept of intentional pedagogy.

Discussion: Engaging Students Using *Stone to Silicon*

Husick noted that American schools may separate out too early children who do math/science from those who do humanities. He would prefer if we offered a more balanced and interdisciplinary curriculum. While concern is often expressed that we're not producing enough graduates in science, math, and engineering, what we've actually failed to produce is innovators. Our students are and want to be innovative. We need to give them environments in which they can try and fail, as all innovators do.

Problem-solving exercises, where students are asked to solve a problem in a different way, are useful in teaching creativity. Biographical narrative is a good way to teach by example. How do innovators view the world and choose and approach problems? One can also have a Rube Goldberg-like contest. Goldberg is a hypothetical inventor who invented strange and different ways of doing common tasks. To empty a bucket of water, you might mount a boot on a wagon wheel and have that boot turn with the wheel and kick the bucket over at the end of a long series of other events. You don't have to actually build these devices, you can just draw them and come up with new ways to do common tasks.

Brainstorming a problem is a great tool. Put all the ideas produced on the board, then do rank-and-select criticism. Then build the finalists, or if this is beyond your resources, describe and draw, or have students present the solution in a Powerpoint. Then demo it, and if time permits, have a reflective process so students can further fine tune what they have done, identify pitfalls, and streamline the process. Solving one problem usually creates others. What new problems were created? Consider unintended consequences, and who the stakeholders are or might be.

Social and technological change in american and western history

Alex Wright, author of *Glut: Mastering Information through the Ages*, observed that we tend to understand the information age in terms of a set of fairly recent technologies. He suggested that we instead compare it to earlier periods when new information technologies emerged. Throughout history, these have seemed to emerge when humanity's living conditions were undergoing sudden, drastic change. During the First European Ice Age, people were forced to live together in much closer quarters and in larger settlements. They developed symbolic objects like jewelry and cave paintings to negotiate social relationships with people they didn't know well.

Twenty thousand years later, the invention of alphabetic writing in Mesopotamia was accompanied by another environment shift, as people started living together in yet larger agricultural settlements. Alphabetic writing brought a schism between the older, oral culture and the new literate culture.

At the end of the Roman Empire, the earliest "book" emerged. The codex, from the Latin word for a bundle of wood, was portable, and unlike a scroll, it could be opened to any page; it's an inherently random-access technology that can be indexed and cross-referenced. The codex reshaped the structure of Western thought and facilitated the early forms of mass production and the concept of a more secular literacy that would plant the seeds for the Gutenberg revolution.

For centuries after Gutenberg's revolution, even though there were advances in the technology of printing, literacy was still restricted to the number of people who could afford books. The roots of today's mass literacy awaited the Industrial Revolution, which brought steam-powered printing presses and an explosion of printed information. New printing technologies both fueled and responded to the emergence of public education and the new demand for things to read. As libraries grew, more sophisticated systems for managing all this information were needed.

Even before computers were actualized, there's been a utopian ideal of the computer as a tool for managing our collective intellectual output. The earliest description of a hypertext-like information environment is from Charles Cutter, a Boston librarian who in 1883 envisioned the library desk of 1983 as having a keyboard attached and a wire coming out. Someone could type something in and have a document appear on the screen. In 1938 H.G. Wells wrote "The World Brain," imagining a future networked computer environment where people could create and share information. He even suggested that the whole thing might become intelligent. Teilhard de Chardin, a French Jesuit, had similar ideas. He found an enthusiastic underground following among his fellow Jesuits, one of whom, Marshall McCluhan, took it as a foundation for his own idea of the global village.

Paul Otlet (1868-1944), a Belgian, actually tried to build something like this. A bibliographer and entrepreneur, he had an insight into the possibilities of networked information while working with Henri La Fontaine, a future Nobel Peace Prize winner. The two saw the proliferation of published knowledge as a threat to intellectual endeavor, making it more difficult to keep track of developments in a given field. They sought to create a universal library. Otlet realized that a lot of information was trapped in books, magazines, newspapers, pamphlets, photographs, moving pictures, even phonographs. He developed a framework for extracting that information. Unfortunately, the Nazis destroyed most of his work.

Another prominent forerunner of the Web was Vannevar Bush, who in 1945 proposed the idea of a memex. A lot of scholarship, in his view, involved comparing documents, linking them together, and then annotating that link. The memex was two screens on which a user could bring up one document next to another and link them. On another screen, the user could annotate that link. Bush described this as a new form of an encyclopedia with a mesh of associative trails. Eugene Garfield, a librarian and indexer, was deeply influenced by Bush's essay. He invented the Science Citation Index, which gave more weight to a heavily cited paper than to a less cited document. That idea would eventually find expression in Google.

Other important innovators in information technology include Doug Englebart, who invented the first working hypertext online system (NLS) in 1968, and Ted Nelson, who saw a huge unrealized opportunity for computers to support the humanities in addition to science and math.

On the Web today, a lot of these storylines come together, particularly in social networking. People are using these tools to negotiate social relationships with people they don't know. They use iconic symbolism to represent themselves and display their friends and groups they associate with. A lot of what they're doing also has to do with oral culture. These older patterns of interaction can help shed light on our understanding of the present-day information age.

Teaching Innovation — A Panel Discussion

Lawrence Husick, Senior Fellow, FPRI led a panel discussion on how to make the history of innovation interesting, relevant and enjoyable for students. Panelist **Joy Hakimm**>, author of *The Story of Science* and *A History of US*, noted that while we live in the greatest scientific era ever, we are not teaching our students about it. Starting around 1905, not only did Einstein discover that atoms existed, but we came to understand their inner workings—the neutrons, protons, and incredibly tiny electrons. We never got a picture of an atom until the 1980s, with electron microscopes. How we invaded the subatomic, quantum world is one of the greatest intellectual feats in history, but we're not telling students about it. True, the math is difficult, but we can understand the underlying ideas. Teaching today's science and innovation forces us into a new kind of teaching and learning with students, but it can be presented in compelling narrative form.

Dennis Shasha, professor of mathematics and computer science at NYU, explained how he uses puzzles, which he has published in book form, to get students and teachers to like math again. As an example, in his early computer work, he recognized that designing circuits that would detect other circuits when they failed was essentially a matter of detecting an occasional liar. He devised a puzzle that demonstrates this. A camp scout leader and eight scouts are on a path. They come to a crossroads where their path meets four more. The campsite is a 20-minute walk down one of the paths, but the leader can't remember which. He wants the scouts home before dark. He knows that two of the eight scouts sometimes lie, but not which two. How does the leader assign the eight scouts to help him explore the four paths in a way that minimizes the risk of the two liars being assigned together and falsely reporting a path as good or bad? Or, in an architecture problem, design a one-story ranch house that has as many rooms as possible but no hallways, where each room has four doors, and one can get from one room to another through at most six doors. The teachers worked the solutions to these and other puzzles in teams.

Paul Dickler, Senior Fellow or FPRI's Wachman Center, distributed classroom lessons available at **/education/classroomlessons.html** that can be adapted into teachers' existing curriculum. He also suggested challenging students to think about how to solve actual world problems in multiple ways. For instance, countering climate change could be done by reducing CO2, increasing photosynthesis, reducing the amount of sunlight that reaches the earth, etc. Have students brainstorm possible solutions.

Husick concluded by noting that Philo T. Farnsworth, who invented the television, was a farmer and self-taught engineer who got his idea for vacuum tubes from furrows in a field. Ideas can come from anywhere, and play is a great way to encourage creativity.

Innovation and Invention: the Computer as a Case History

Husick and Shasha discussed how the history of the computer could be presented to students as a narrative of innovation. The first digital computer, Colossus, was built by the British Signals Intelligence Office in 1942-4 at Bletchley Park to decode German messages from the Enigma cipher machine. (The University of Pennsylvania unveiled ENIAC, the first electronic computer, in 1946.) For his book *Out of Their Minds: The Lives and Discoveries of 15 Great Computer Scientists*, Shasha interviewed seminal thinkers in computing such as John Bacchus, who designed the first widely used computer language, Fortran. Bacchus simply wanted to make the tedious early programming process easier. The logic parse trees involved in this can be taught as a language exercise.

Husick himself started using computers just as the PC was coming out. He didn't intend to become so involved, but was a chemistry major who had research data representing hours in the field from which to write his thesis. His Sears digital calculator didn't have memory, didn't do square roots, and had only eight digits. He eventually gained access to his college's Digital Equipment Corp. PDP 1170, which took up a whole room. After a crash weekend with a friend learning Fortran, he started using the DEC, along the way learning how to do programs that would do simulations of chemical equations. He got a job at Computerland just for the computer access the job permitted, and got to meet and work with early computing leaders like Steve Jobs, Steve Wozniak, and Allen Kaye. The film *Pirates of Silicon Valley* will give students insights into this generation of innovators. One could say that we only have today's PCs because there were early computer lovers who wanted their own computers. The computer is so important to students, the history of how we got here naturally engages them.

War and Technology

Alex Roland, professor of history at Duke University, used technology and war as a context for thinking about the concept of technological determinance. He put forward four propositions. First, *technology shapes warfare*, but it is *war* (not the actual conduct of it) that shapes technology. In preparing for war, societies and states promote technological innovation that often spills out into and transforms societies as well.

However, his second proposition was that *technology does not determine warfare*. It establishes neither how warfare is conducted nor how it will turn out. That is because nothing in history is deterministic. To believe in determinism is to believe in inevitability.

Among instances in history where technology appeared to determine the nature and result of warfare is the chariot, which came out of nowhere between 1800-1750 BCE. It appears it was invented by Eurasian steppe warriors and then spread through the Anatolian plain and into the Levant. It became the dominant weapon on Western battlefields. Nothing could stand up to it, and the states that encountered it felt they had to raise their own chariot armies. Chariot warfare culminated in the battle of Kadesh, in which Pharaoh Ramses II fought Hittite chariot corps to an indecisive draw. It's estimated that there were 4,500 or 5,000 chariots on that battlefield. These chariots were ruinously expensive. Not only did you need to build the chariot itself out of wood in a region of the world where there is no wood, but you also had to have four horses and four more in reserve for each chariot, all in the Fertile Crescent, which doesn't support horses. But nonetheless, everyone, if they wanted to be a great power, had to develop a chariot.

Then, almost overnight, around 1200 BCE, the chariot disappeared from Western warfare. Some scholars think that the states of the Levant simply bankrupted themselves trying to maintain these chariot corps. William H. McNeill thinks it was the introduction of iron, which appeared in the West in tools and infantry weapons at about the same time. Robert Drews blames what he calls the catastrophe. Almost exactly at this time there was a massive rolling migration out of the Eurasian steppe. As this migration occurred—which seems to have been driven by some eruption, whether warriors pushing against other states or some climatic or environmental catastrophe—it destroyed cities all along both coasts.

We know from later warfare—from Alexander the Great and the Romans—that it is not difficult to defeat chariots. All you need is troops who will stand up to them. The horses will stop before they will run through a line of humans. So all the time the citizens of the Levant were accepting the chariot revolution, they didn't have to. As soon as the secret was out, the chariot migrated to the east. It was not at all predetermined.

That leads to the third proposition, that the better conceptual model for thinking about the impact of technology on warfare is the open door. Lynn White Jr. introduced this concept in *Medieval Technology and Social Change* (1962). He took up the Brunner thesis, an argument by German historian Heinrich Brunner that Charles Martel, the grandfather of Charlemagne, brought in the feudal system when he realized at the Battle of Poitiers (732 CE) that his heavily armed and armored mounted knight was the appropriate model for European states to defend themselves against the lightly armed and armored invaders. Martel began confiscating church property to give to his knights so they could earn income from the land to pay for their equipment, training, and retinue in return for a promise of military service to the state.

White observed that Martel had started confiscating church land before the Battle of Poitiers and concluded that it was the stirrup, which was introduced in the West at almost exactly this time, that made the heavily armed and armored mounted knight an undefeatable force on the battlefield. White has been accused of technological determinism, but he wasn't trying to say that the stirrup created feudalism, only that it was a catalyst. Technology opens doors; people decide whether or not they are going to go through them. This is a useful tool for thinking about technology because it introduces agency. In military histories, technology is too often a *deus ex machina* that suddenly appears on the battlefield and changes everything. We need to restore human agency to all stories of technology.

We cannot know who invented a premodern technology, or how or why. In the modern world's military-industrial complex, the same people who use the technology shape the mechanism by which the technology is created. That brings us to the fourth proposition, that it's easier to comprehend this phenomenon in the modern than the premodern world. Beginning around the time of the French Revolution, we see a more systematic effort by states to promote technological innovation for warfare. They've left a historical record of where these inventions came from, who opened the door, and why.

Innovation and the Growth of the American Economy

David Hounshell, professor of technology and social change at Carnegie Mellon University, looked at technological change as a driver of economic growth and outlined changes over time in how we have perceived who is responsible for innovation.

Austrian economist Joseph Schumpeter (1883-1950) held that the entrepreneur is responsible for innovation, which he defined as “any doing things differently in the realm of economic life.” Schumpeter identifies the entrepreneur as the person who makes new combinations and carries them out. Schumpeter plays down the significance of the inventor since mere invention is insufficient for economic growth. The entrepreneur is the person who pushes innovation into a usually resistant marketplace.

In *Instability of Capitalism* (1928), Schumpeter recognized that the West had been moving away from competitive capitalism toward what he calls trustification. Where in competitive capitalism, individuals made innovations, under trustified capitalism, it’s industrial R&D laboratories. By soon after his classic *Capitalism, Socialism, and Democracy* (1943) was published, these corporate R&D laboratories looked like a juggernaut. Schumpeter saw that they had solved the problem of innovation, and yet was concerned that they were monopolies.

Why is innovation important? In “Technical Change and the Aggregate Production Function” (1957), Robert Solow, an economist at MIT, examined the sources of productivity growth in U.S. history and concluded that when you look at all the increases in labor and capital inputs and overall productivity growth, only some 40 percent of this can be accounted for through Schumpeterian competitive capitalism. There is a residual technological change that he argued was the principal source of economic growth. Solow won the first Nobel Prize in Economics for this work, which has been a foundation of economists’ work ever since.

The Constitutional Congress, after debating who was responsible for innovation, gave Congress the power “To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries.” This was a strict construction for federal responsibility for innovation at least initially. Over time, our perception of the federal government’s involvement in the promotion of science and technology has changed. During the Cold War, if society had a problem, we thought the federal government, particularly the military, should solve it. Today, we would go to the market. In 1940, it would have been to the highly centralized, well-organized industrial R&D laboratories. In 1870, it would have been to what we would call the professional, independent inventor.

In 2000 industry was actually spending more money on R&D than ever before, and much more than government. But the perception is that we’re moving toward a market relationship. In the 19th century, innovation was a matter of market relationships until firms got bigger and began to think about vertical integration—that is, incorporating innovation into their firms rather than relying on the market. This would lower the cost of innovation, reduce uncertainties, and respond to federal laws, in particular the Sherman Antitrust Act of 1890. Corporate research laboratories emerged, gained strength, and reached their pinnacle roughly in 1950. They began to disintegrate roughly in 1975. Some of the disintegration has to do with information technology, and a lot has to do with public policy. In 1980, the Baye-Dole Act allowed universities to begin to patent and marketize innovations that came out of government-funded R&D. That was a response to the competitiveness challenge Japan posed at the time. In 1984, the Reagan administration gave corporations permission to conduct joint R&D on a pre-competitive basis. These are important public policy changes in response to perceived threats to the nation’s security.

The emergence of the Kauffman, Lemelson, and other foundations in this area manifests concern that the U.S. is not being sufficiently innovative and that individuals bear responsibility for innovation, that we need to train our students to be innovative, to equip them with the tools to be innovative. That reflects our own times. We may swing back to a much more heavily corporate or government-oriented view of who is responsible for innovation.

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